Probing Europa's Hidden Ocean From Tidal Effects on Orbital Dynamics

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Indirect observations of Europa suggest that the Jovian satellite may have a liquid ocean underneath its ice surface. Since under tidal forcing a body with internal fluid layers deforms more than an otherwise similar but solid body, one possible way to detect an existing ocean is to measure the potential tidal Love number k_2 through its dynamic effect on the trajectory of a low Europa orbiter (*e.g.* Yoder, 1999, in press). Our study assesses strategy and accuracy for such an experiment to detect the ocean and to infer its depth.

Based on current knowledge and expectations about Europa, we first constructed a series of geophysical tidal response models to describe static deformation of non-rotating, spherically stratified Europa with various models of internal structure. The results are k_2 as functions of interior parameters. The difference in k_2 between cases with and without an internal ocean is very striking. Depending on the total thickness of ice and ocean, the k_2 dependence on the ocean depth can also be significant.

We carried out consider covariance analyses to determine measurement accuracy for k_2 and other dynamic and kinematic parameters in a fairly realistic way. The analyses assume an orbiter in a nearly-circular and high inclination orbit with 200 km altitude. The orbit determination procedure uses X-band two-way Doppler tracking from 2-3 DSN stations on Earth for 4 to 15 days in separate 0.5 to 4 day arcs. Europa's gravity coefficients are estimated up to degree and order 50 along with a constant k_2, lag angle, certain radiation pressure parameters, and arc epoch states. Degree 51 through 60 gravity coefficients and other radiation pressure parameters are considered to assess their effects on estimated parameters. The magnitudes of the higher degree gravity field are represented by Kaula's rule scaled by a planetary factor and the consideration about the top layers of ice and water. Our results show consider uncertainties for k_2 at the level around 0.001 or better, depending on tracking scenario and noise assumed for the data. The tidal lag angle accuracy is at the level of 0.1 degree or better. Perturbations from uncertainties in the solar and Europa radiation pressure models are minimal. These results are encouraging because they suggest that the experiment might both detect the presence of the liquid ocean and put a meaningful bound on its depth with tidal Love h_2 number and libration measurements.

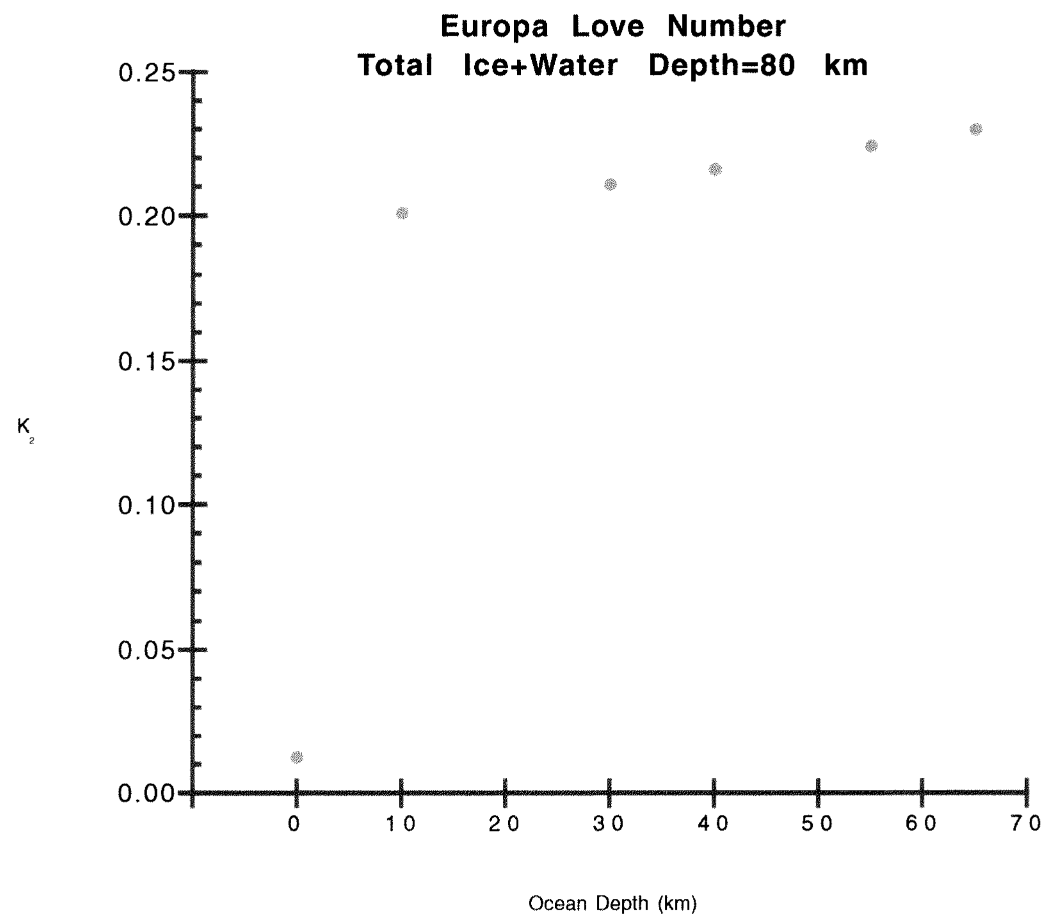

Figure 2. Tidal k2 Love number as a function of ocean depth. The total ice+water thickness is assumed to be 80 km here.

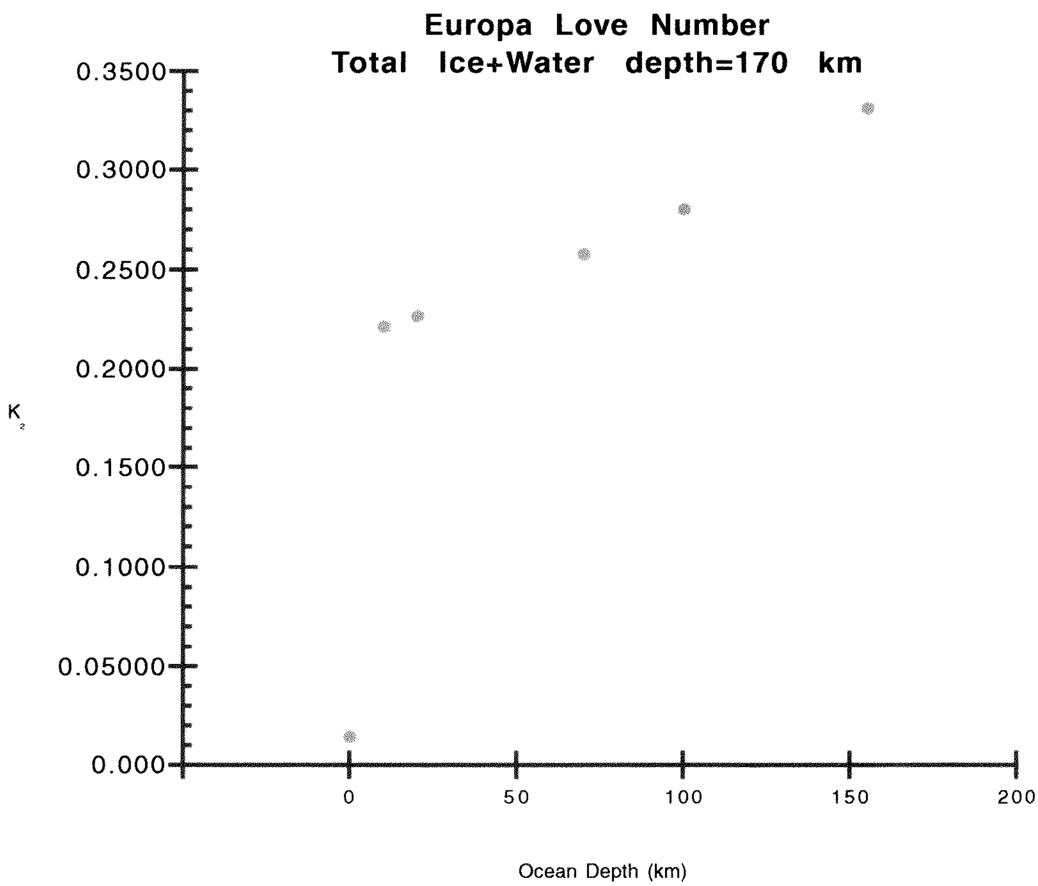

Figure 1. Tidal k2 Love number as a function of Ocean Depth. The total thickness of ice+water is taken to be 170 km.

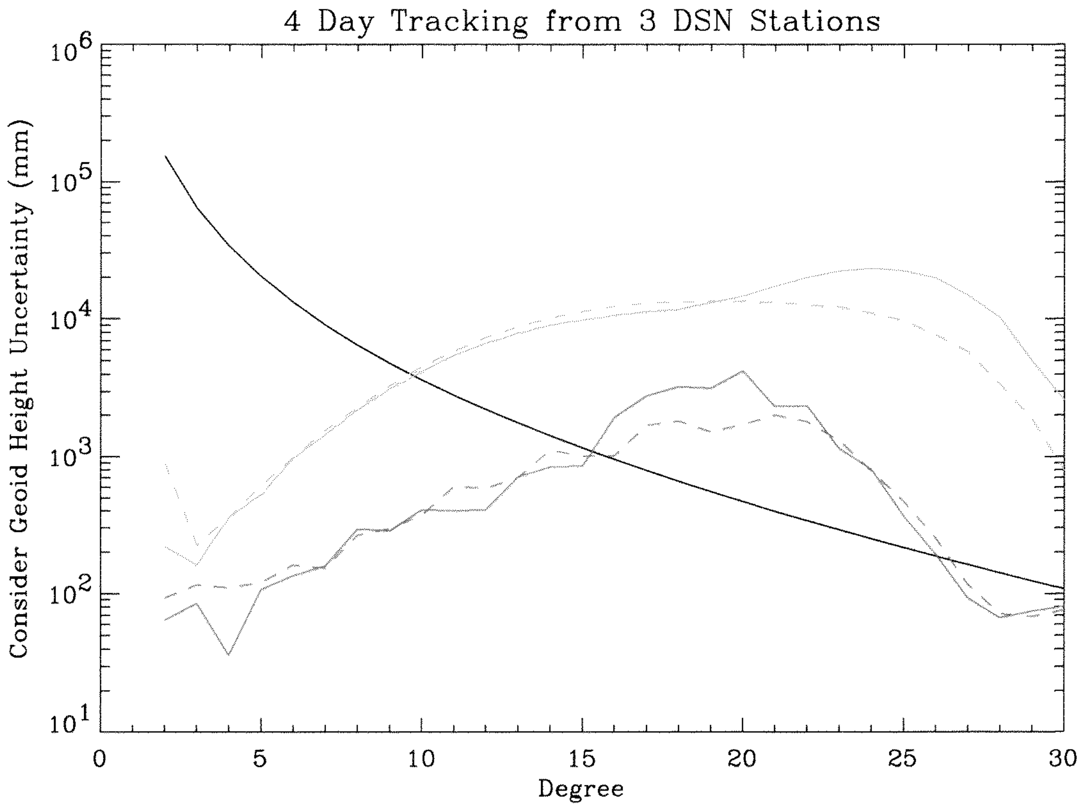

Figure 4. Similar to Figure 3 but for shorter data span. 3 DSN stations are used and the maximum solved for degree is reduced to 30.

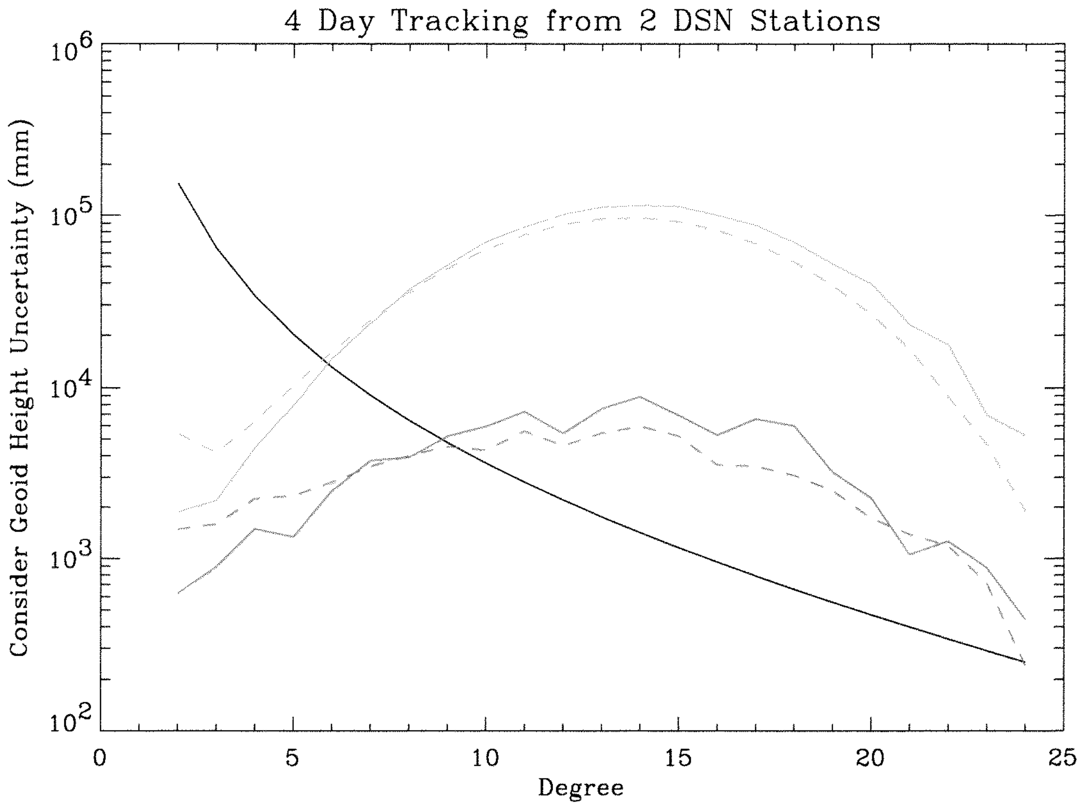

Figure 5. Similar to Figure 3. But with only 2 DSN stations. The maximum solved for degree is 24.

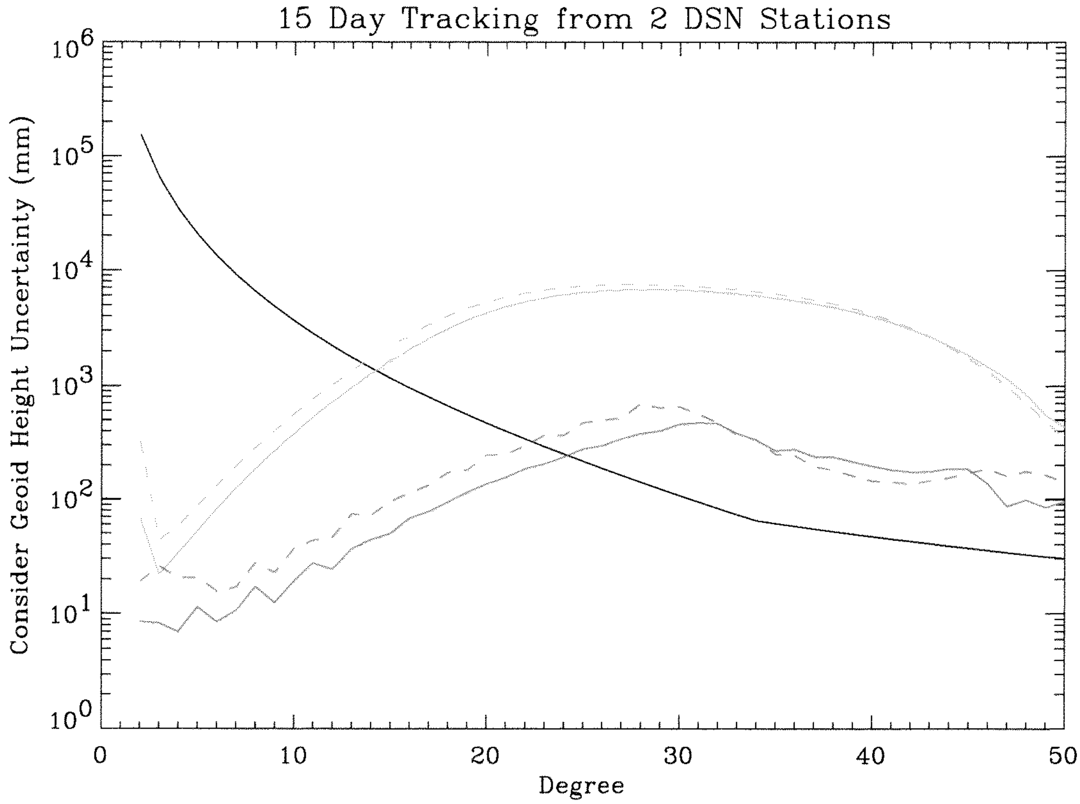

Figure 3. Consider covariance results for Europan geoid harmonic coefficients. Red curves are for RMS uncertainty of each degree, green lines are for minimum uncertainty within each degree. Solid and dashed lines are results from 3.5 day and 0.5 day arcs respectively. 15 days of tracking from 2 DSN stations are assumed.

Table 1. Consider Covariance Analysis Configuration

Parameter	Symbol	Value	Note
X-band Doppler noise	σ_f	3×10^{-13}	tcount=30 s
Sun-Orbiter plane viewing angle		318°	
Earth-Orbiter plane viewing angle		328°	
Orbiter Altitude	h	200 km	
Orbiter Eccentricity	e	0.01	
Orbiter Inclination	I	83°	
Orbiter Node	Ω	220°	
Orbiter Arg. of Periapsis	ω	30°	
Orbiter Period	T	2.3 h	
Orbiter Mass	m	400 kg	
Minimum DSN Elevation Angle	elmin	15°	

Table 2. Consider Uncertainties (15 Day Tracking-2 Stations)

Parameter	Symbol	Uncertainty		Unit
		3.5 Day Arc	12 Hour Arc	
Europa	GM	3×10^{-11}	1.2×10^{-10}	km^3/s^2
Stokes Coefficient	C_{20}	3.8×10^{-8}	1.9×10^{-7}	
Stokes Coefficient	C_{21}	1.2×10^{-8}	2.5×10^{-8}	
Stokes Coefficient	S_{21}	5.4×10^{-9}	1.2×10^{-8}	
Stokes Coefficient	C_{22}	6.2×10^{-8}	2.9×10^{-7}	
Stokes Coefficient	S_{22}	6.7×10^{-8}	3.1×10^{-7}	
Love Number	k_2	0.0004	0.0016	
Lag Angle	ν	0.03	0.16	deg
RMS Epoch Radial Pos.	X	5.7	21.8	m
RMS Epoch Transverse	Y	4.2	24.6	m
RMS Epoch Normal	Z	8.6	47.3	m
RMS Europa Orbital Element	a	1.0	2.8	km
RMS Europa Orbital Element	e	1.5×10^{-8}	1.2×10^{-6}	
RMS Europa Orbital Element	I	7.2	30.3	arcsec
RMS Europa Orbital Element	Ω	10.0	24.1	arcsec
RMS Europa Orbital Element	ω	8.9	22.0	arcsec
RMS Europa Orbital Element	M	0.2	14.3	arcsec

Table 3. Consider Uncertainties(4 Day Tracking-3 Stations)

Parameter	Symbol	Uncertainty		Unit
		3.5 day arc	12 hour arc	
Europa	GM	1.1×10^{-10}	3.1×10^{-10}	km^3/s^2
Stokes Coefficient	C_{20}	1.5×10^{-7}	4.9×10^{-7}	
Stokes Coefficient	C_{21}	6.0×10^{-8}	1.0×10^{-7}	
Stokes Coefficient	S_{21}	4.1×10^{-8}	5.9×10^{-8}	
Stokes Coefficient	C_{22}	2.0×10^{-7}	9.0×10^{-7}	
Stokes Coefficient	S_{22}	1.7×10^{-7}	7.6×10^{-7}	
Love Number	k_2	0.0008	0.004	
Lag Angle	ν	0.1	0.5	deg
RMS Epoch Radial Pos.	X	19.9	57.9	m
RMS Epoch Transverse	Y	11.57	52.4	m
RMS Epoch Normal	Z	17.4	99.8	m
RMS Europa Orbital Element	a	1.4	2.4	km
RMS Europa Orbital Element	e	2.2×10^{-8}	3.4×10^{-7}	
RMS Europa Orbital Element	I	10.8	27.6	arcsec
RMS Europa Orbital Element	Ω	13.6	22.8	arcsec
RMS Europa Orbital Element	ω	11.9	20.5	arcsec
RMS Europa Orbital Element	M	0.22	8.2	arcsec

Table 4. Consider Uncertainty(4 Day Tracking-2 Stations)

Parameter	Symbol	Uncertainty		Unit
		4 day arc	12 hour arc	
Europa	GM	4.8×10^{-10}	2.4×10^{-9}	km^3/s^2
Stokes Coefficient	C_{20}	1.8×10^{-6}	3.8×10^{-6}	
Stokes Coefficient	C_{21}	6.0×10^{-7}	1.4×10^{-6}	
Stokes Coefficient	S_{21}	4.0×10^{-7}	9.5×10^{-7}	
Stokes Coefficient	C_{22}	1.4×10^{-6}	4.8×10^{-6}	
Stokes Coefficient	S_{22}	1.2×10^{-6}	4.5×10^{-6}	
Love Number	k_2	0.005	0.02	
Lag Angle	ν	0.7	2.5	deg
RMS Epoch Radial Pos.	X	87.1	451.7	m
RMS Epoch Transverse	Y	41.4	297.6	m
RMS Epoch Normal	Z	57.8	593.9	m
RMS Europa Orbital Element	a	2.7	6.3	km
RMS Europa Orbital Element	e	7.6×10^{-8}	6.4×10^{-6}	
RMS Europa Orbital Element	I	39.4	30.7	arcsec
RMS Europa Orbital Element	Ω	26.9	26.2	arcsec
RMS Europa Orbital Element	ω	24.2	25.1	arcsec
RMS Europa Orbital Element	M	0.69	24.9	arcsec